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CHAPTER 9

INSTRUMENTATION AUTOMATION TECHNIQUES

Section I. Introduction

9-1. Introduction. Instrumentation automation is increasingly becoming a valuable means of collecting instrument data for several reasons. Primarily, some tasks that are traditionally done by instrumentation personnel are better accomplished by machines, for the fact that the machine will take measurements in the same manner at each reading, whereas human error can cause minor variations in reading and interpreting data. Automation permits a greater volume of data to be collected in a given period of time. Where an instrumentation reading party may take 4 to 6 hours to read a set of plumblines, the same readings can be taken in less than 10 minutes when collected by automated plumbline monitoring equipment. The cost of instrumentation and computers to montior these instruments has decreased drastically within the past five years. It is now more economical, in terms of overall cost, to automate the reading of certain types of instrumentation than to continue reading them by manual methods.

9-2. Scope. This chapter describes the steps necessary for implementing automated instrumentation monitoring systems suitable for use in or at large concrete structures. It covers the sensor selection, data transmission, data conversion, data manipulation, data display, and data storage. The definition of system requirements, and a sample "Systems Requirements Document" to serve as a guideline in specifying the system's functional requirements, are also presented. This chapter discusses key factors that must be considered as the system develops. System considerations in determining measurement techniques, component compatibility, system characteristics, interfacing techniques, power sources, grounding techniques, maintainability, operability, system calibration, system flexibility, sensor selection criteria, transducer hazards, signal conditioning techniques, data transfer, data processing, data display, and recording and storage techniques are covered. The information presented in this chapter is condensed from a more detailed report entitled "Instrumentation Automation Techniques". That report is one of three reports on instrumentation automation for concrete structures published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Program.

Section II. System Requirements Document

9-3. Defining the Objectives. A logical approach to specifying operating requirements for any data collection and reduction system is to first define the broad objectives of that system. Answering several simple questions will assist in identifying these objectives:

- What information is needed?
- How often does the information need updating?
- In what form does the information need to be presented?
- What is the relative economic value of the information?

By defining the scope of the information needs, an engineer may begin the task of specifying the general requirements of an instrumentation system to satisfy those needs.

All system operating requirements may be broadly categorized into two types: 1)functional and 2)environmental. Functional requirements include system operating parameters that are related to or influenced by functions of hardware and software. Environmental requirements include all systems operating parameters that are influenced by external conditions, such as the natural and induced physical environment, and spatial distribution/constraints related to system installation.

b. The proper vehicle for describing the scope of the system needs is the system requirements document. This is a document that serves as a guideline in determining the system functional and environmental requirements. In it, the needs of the system are documented. The phenomena to be measured is defined and quantified, and each component of the system to be designed is analyzed to be certain that its requirements are fully defined and documented. A sample of a requirements document is presented in Appendix D.

9-4. Functional Requirements.

a. Defining the Measurement. The process of breaking-down the physical phenomena to be measured into their fundamental quantities of length, time, mass, and temperature enables the engineer to better define the best type of measuring component (transducer) for the instrument system. In other words, the engineer should explicitly define and examine the non-electrical quantities that must be converted to usable electrical signals. Ultimately, these electrical signals must reliably and-accurately represent the value of physical quantities being measured. *

* b. Defining the Level of Need.

(1) Sample Rate and Frequency of Interest. An automated electronic data collection, processing, and storage system performs these functions at high throughput rates and can compile enormous amounts of information. The engineer must determine the frequency at which any given parameter must be measured, processed, and recorded. Typically, data are collected on a predetermined time schedule, or when a predetermined setpoint has been exceeded.

(2) The use of programmable, microprocessor-based data acquisition systems (DAS) and test equipment provides the user with flexibility to easily modify measurement rates (sample and process speed) with software, and expand data storage capacity (memory or magnetic disk). System process speed is not a critical consideration for accurate measurements of relatively slow changing quantities, such as temperature, deformation and strain. However, if an accurate time history of rapidly changing phenomena (active seismic data) is required, the system sample and process rate becomes critical. Generally speaking, the sampling frequency and system response should be an order of magnitude greater than the maximum data frequency expected to be recovered by the system.

c. Signal Distribution and Acquisition.

(1) Distribution and acquisition of electronic signals from numerous sensors and instruments require one of two primary approaches for system architecture. A centralized system is generally recommended if the application is small, with signal sources close together. However, larger applications, where instruments are geographically dispersed (typical of large dams), may require remote processing or distributed intelligence in the data acquisition system architecture. Wiring costs can be a large factor in determining the proper type of system.

(2) In a centralized DAS, all signal processing takes place in or next to the computer chassis with field wiring and cabling providing the signal link from sensors to processor. A centralized architecture keeps the amount of software needed to a minimum. However, wiring and cabling may be expensive and prohibitive unless all sensors are relatively near the computer, and if the central unit fails, or is down for maintenance/program modification, the whole system is inoperative.

(3) For environments too harsh for a computer, or where applications are physically spread out, a distributed architecture is recommended. The two types of systems in this category are those with remote front ends, and those with distributed intelligence. These systems reduce wiring costs by *

* processing the signal close to the sensor, and transmitting the results to the central unit over less expensive wire. Added costs from these systems come from the remote processors.

d. Reliability and Criticality. System reliability in automated electronic instrumentation is influenced by five primary factors. The level to which each is implemented influences overall cost and must be considered in establishing this requirement. They are as follows:

(1) State-of-the-Art Equipment. As a general rule, use of more recently developed instrumentation increases system reliability, and generally reduces the total cost of data over the life of the system.

(2) System Complexity. As the number of subsystems increases, instrumentation system reliability generally decreases. Consequently, simplicity or minimal complexity is recommended in design and integration.

(3) Environmental Conditions. System reliability generally decreases with increased severity of environmental conditions to which the components are exposed. Subsystems involving critical measurements should be environmentally protected wherever possible.

(4) Operating Time. All active components have a limited operating life. Reduction of continuous operating requirements to intermittent or cyclic functions generally extends the life of subsystem components.

(5) Preventive Maintenance. Proper and periodic maintenance increases system reliability and extends operating life.

Consideration of these reliability factors is very important in applications that: 1) monitor critical functions over extended periods; 2) have components that cannot be easily replaced; or 3) do not have skilled maintenance personnel readily available. Component redundancy to increase reliability to an acceptable level can solve this condition.

e. Resolution and Accuracy. The term "measurement resolution and accuracy" simply implies to what degree the measured value represents the "true" quantitative value. With respect to instrumentation systems requirements, the engineer must clearly define the degree to which measured quantities must reflect actual values in order to provide adequate information to satisfy the need. Typically, there is a direct relationship between cost and the degree of measurement accuracy and resolution. The measurement accuracy and resolution requirement should reflect the relative economic value of the desired information. *

* f. Computation Requirements. The engineer must make a reasonable estimate of the volume, speed, and complexity of computations that an automated data collection and reduction system will be required to perform. Simple conversions and mathematics may be performed by individual hardware elements (analog signal conditioning and recording devices) in one and two data-channel systems. However, for automated multi-channel, multifunction data acquisition and processing, a microprocessor-based instrumentation system and supporting software is recommended. The major considerations for the engineer are identifying: 1) maximum system operating speed and storage capacity requirement for programs and data; and 2) available sources of system operating software.

g. Power and Power Conditioning Requirements. An automated electronic system requirements list must include considerations for power provisions. The factors that are pertinent include:

(1) Specific power requirements for individual instruments, to include requirements for current usage. Most instruments that require direct current contain internal power supplies or batteries with line charge capability.

(2) Alternative direct current power sources (batteries, photovoltaic cells, etc.) and power inverters must be installed if the electronic system is likely to be located in a remote area with no available line power.

(3) The relative economic value of a data loss must be weighed against significant costs for backup computer power hardware such as motor generators, uninterruptible power systems (UPS), line isolation, and regulation transformers. If computer back-up or uninterruptible power is not economically feasible, the operating program should be in read only memory (ROM) instead of random access memory (RAM) so that the system will automatically restart after a power failure.

(4) State-of-the-art computer applications routinely use software that collects, processes, and moves data into permanent storage at speeds that prevent more than miniscule loss of collected data if a hardware anomaly occurs.

h. Data Display and Recording Equipment. A basic function of an instrumentation system is to present desired measurement data to the user in a form that satisfies information needs. Thus, the engineer must explicitly define the requirements for acquired data display, storage, or special processing functions such as limit/alarm control. Processed data may be displayed on digital meters, video screens, multi-axis plotters, *

* chart recorders, or tabulated, formatted, and printed in hard copy on command by the user or a preprogrammed schedule by software. Also, all data may be stored on magnetic media for future processing.

9-5. Environmental Requirements. To complete the general requirements for design of an automated instrumentation and measurement system, the engineer must identify the major elements and range of the natural and induced physical environment to which specific subsystems will be subjected during operation. System performance and reliability depend upon the proper match of instrumentation and operating environment. To achieve this end, either the instruments can be fitted to the environment, or the environment can be conditioned to suit the needs of the instruments.

a. Natural Environment. Natural elements of the physical environment include temperature, humidity, vibration, pressure, dust, dirt, etc. The design requirements document should specify instrumentation subsystem components that are functional within a range of each applicable element. The following recommendations deserve particular consideration.

(1) Uncontrolled environmental excursions are generally excessive for typical automated instrumentation. Environmentally controlled enclosures are recommended for computer-based and other sophisticated equipment.

(2) Since exposure duration affects equipment survivability, where environmental conditions are severe, the use of portable data acquisition equipment will limit the equipment exposure to those times it is being used. The equipment might then be returned to a controlled environment for data processing and display.

b. Induced Environment. Induced elements of the physical environment include electromagnetic and electrostatic interference, the technical skill of system personnel, and spatial factors such as geographic and geometric distribution and size limitations of subsystem components. Examples of these are:

(1) Electromagnetic and electrostatic interference, and field sources of electrical signal noise generated by instrumentation power generators. These are damaging to improperly shielded existing subsystems. Identify and minimize large generators of electromagnetic and electrostatic fields and maximize proper shielding and ground plane techniques in retrofitted instrumentation.

(2) Skill level requirements of operation/maintenance personnel are generally a direct function of system complexity. Match the instrumen-

* tation application with available personnel skills to reduce additional training-related costs and hardware/software problems.

(3) Installation of additional instrumentation requires additional space within an allocated area. Consider: 1) Centrally locating system components to facilitate efficient operation and reduce maintenance and interconnection requirements, 2) Make equipment accessible for maintenance, 3) Make instrumentation that requires frequent interaction with a human operator adequately labelled, lighted, and accessible.

Section III. System Design

9-6. System Considerations.

a. Having established the system requirements, a search for system components begins. A primary concern in such a venture is a cost versus performance comparison. A system that meets the minimum cost/performance ratio requirements now might not meet future requirements. Future expanion should be evaluated into the decision. It is best to select a system that may have specifications and capabilities beyond the current requireents to allow for future needs.

b. The stability of a manufacturer and the extent of his support are of great concern. If a manufacturer goes out of business or cancels the product line, problems with spare parts, maintenance, and expansion can arise. Talking with other users of like or similar systems provides a good input for rating a manufacturer. A check of the company's financial standing is also recommended.

c. System architecture influences speed and ease of access to the system. Central Processing Unit (CPU) speed is rated by width of bit units and cycle time. The data paths internal to the CPU are rated as 8-, 16-, or 32 bit units. The wider path is capable of handling larger numbers faster. Computer time is measured in CPU clock cycles. Each instruction requires a certain number of cycles; therefore, the time required for a process is the number of cycles required multiplied by the cycle time. The power of a computer is also determined by its instruction set. The more powerful an instruction set, the more powerful the computer.

9-7. Automated Measurement Techniques.

a. Digital computers now available provide the best means for acquiring and processing measurement information. The size and cost of the system will depend on the extent of processing, and the number and *

* frequency of measurements. If storage is the only purpose of a system, the cost is low. Costs increase with system complexity and size.

b. A measurement is made by an element or transducer which produces a voltage, current, or frequency that represents the quantity or property being measured. This is accomplished by varying inductance, light, capacitance, or resistance. The output must be digitized for use by the computer system. It may be digitized at the source before transmission, or later at the system. Care must be employed in the transmission of the signal if they are digitized at the system. Transmission of digital signals have a high noise immunity, and may be checked to assure that what is transmitted is what is received. Low-level (mV or below) analog signals are the most critical in high-noise environments.

c. Computer systems offer means to calibrate and compensate for system errors to assure accurate readings. Most DAS manufacturers offer signal conditioning with multi-channel analog-to-digital (A/D) converters. Depending upon the type of input device, signal conditioning consists of amplification, bridge completion networks, thermocouple compensation, excitation voltage and current supplies, and filtering. The more accuracy and precision required, the more the system costs. Also, maintenance and calibration costs rise. Therefore, only the minimumal accuracy and precision required should be specified.

9-8. Component Compatibility. In choosing components for a system, beware of the manufacturers' exaggerated claims of compatibility and performance. The best way to determine compatibility is to connect the units and observe their operation. However, when this is not possible, a competent engineer or technician should check specifications of all parameters for compatibility. Try to avoid special interfaces and special software drivers as they are expensive and difficult to maintain.

9-9. Instrument/System Characteristics.

a. Matching the instrument to the system is a critical part of system integration. For voltage output instruments, if the voltage level of the instrument does not match the voltage level of the system input, signal conditioning must be added. Some systems provide various levels, ranges, and resolutions with programmable gains. These and other forms of signal conditioning add to the cost of a system, and should only be specified when necessary.

b. If an excitation voltage is used, the system should be able to read this voltage for calibration purposes. The distance between the transducer and the system is a consideration because of line loss and in- *

* terference. Signal drivers, shielding and filtering may be necessary to reduce electromagnetic interference (EMI) on long leads. This is especially true in harsh electrical environments.

9-10. Interfacing Techniques. Using standard interfacing techniques is recommended since nonstandard interfaces make system integration a difficult task. There are two basic types of interfaces: serial, and parallel. Choosing an interface technique depends on distance, required transmission speed, and environment.

a. Serial. The Electronics Industry Association (EIA) RS-232-C standard is the most popular serial interface. Its limitations are distance and numbers of devices (17 meters and 1 device). Baud rates (bits per second) of 19.2 kbaud are possible. The EIA RS-422 standard interface is a differential version of the EIA RS-232-C standard. It is capable of transmitting over longer distances and at higher speeds (100 meters and 100 kbaud), and has better noise immunity. The EIA RS-449 standard serial interface has good noise immunity and baud rate (100 kbaud at 1200 meters), but handshaking slows the throughput rate. The 20-mA current loop is also a popular serial interface that may be used for transmission of data up to 180 meters at 9600 baud. Fiber-optic links are special serial interfaces. Their major advantages are: speed (10 Mbaud to 1 Gbaud), complete electrical isolation, and no electromagnetic interference (EMI). They are excellent for use in electrically harsh environments. They will transmit over 3 kilometer lengths without repeaters.

b. Parallel. The Institute of Electrical and Electronic Engineers (IEEE) IEEE-488 standard instrument bus is the most popular parallel interface. It is 8 bits wide and is capable of speeds of up to 1 Mbyte/set. Its limitations are distance and number of devices (30 meters and 15 devices). Another low cost interface is the Hewlett-Packard interface loop (HP-IL). This is a very simple two-wire link and is used on instruments, hand-held calculators, and computers. This link uses a loop configuration and can transfer 5 kbytes per second.

9-11. Power Sources.

a. Commercial power is sometimes unacceptable because of excessive noise, voltage fluctuations, and drop-outs. Less severe power problems can be overcome by using line conditioners which regulate voltage, filter noise, and protect against transients. More severe conditions could require the use of a motor-generator set which provides a higher level of line conditioning features. If power failures are intolerable, an uninter- *

* ruptible power system (UPS) should be considered. These systems monitor the input power and switch to a back-up system (battery, diesel generator, etc.) when there is a power interruption.

b. At sites where commercial power is not available, power can be obtained from batteries coupled with generators. System instrumentation should be chosen that operates with minimum power consumption to reduce backup power system costs. Batteries will store the power, and inverters convert the DC voltage to needed 120 VAC. Solar cells, thermoelectric and wind-powered generators may be used to maintain trickle charges on batteries. If available, water-generated energy may also be used. If these sources are not adequate, gas or diesel-powered generators may be installed. Also, power backup and conditioning, to minimize the effects of AC line voltage problems such as transient noise spikes, and dropouts may be required to ensure that a temporary power anomaly does not interrupt or prevent critical data acquisition.

9-12. Grounding Techniques and Lightning Protection.

a. The best system for grounding is to establish a single point for ground which is referenced to incoming power. All grounds should be referenced to this point with heavy gage copper wire. The single ground point should be a copper bar or plate. Analog and digital grounds should be separated except at the single system ground point. Cable shields should be grounded at the source end only. Equipment cabinets should only be grounded through a bus to the single ground point.

b. When it is necessary to establish a ground at a remote site, isolation should be used at the host system end. For digital systems, the least expensive and most effective method of isolation is the opto-coupler. Several isolation amplifiers are available for analog systems. AC signals may be isolated by using isolation transformers.

c. Some form of isolation and line conditioning such as high-isolation power transformers or additional grounding circuitry should be used between the system and commercial power, and in areas where lightning is likely to disturb the instrumentation. This prevents commercial power disturbances and lightning activity from damaging sensitive circuits in both the system and the field instrumentation.

9-13. Maintainability.

a. When reviewing a system design for maintainability, one should check for ease of access to components for test purposes. If the system uses plug-in printed circuit cards, an extender card should be available to *

* aid troubleshooting. If the system has a modular construction, the modules should be of reasonable size and perform a particular function. This enables a "board swapping" approach to troubleshooting and minimizes system downtime. This approach requires stocking of spare boards. If parts are rare and unusual, ensure that the manufacturer can support the unit and that parts lead time is not excessive.

b. Documentation should be clear and concise, yet detailed. It should include a general description, a theory of operation, a block diagram of the unit, installation instructions, a section on troubleshooting, a parts list, and logic or schematic diagrams. Even the best technicians are unable to repair a unit without this basic documentation.

9-14. Operability. The ease with which a system functions determines the level of expertise required by the operator. Controls should be well labelled and easily understood, Try to avoid complex operation procedures. The more automatic the system, the less the chance for operator error.

9-15. System Calibration.

a. System calibration is essential to verify the accuracy of the various readings taken by the system. Measurement errors are the quantitative difference between the true values of the measurand and the values indicated by the measuring system.

b. The most accurate method of calibration is to apply a standard reference quantity to the sensor and adjust the measurement system to the proper reading at several points over the range of the sensor. Two types of reference standards are used in calibration. The primary standard is a standard which is directly traceable to the National Bureau of Standards (NBS) or a natural physical constant. Primary standards are seldom used in field measurement applications, but are used mainly under laboratory conditions. Secondary standards are those calibrated to a primary standard, and are normally used in field calibrations.

C. The most common method of calibration, although less accurate, is signal substitution. In this case, an electrically equivalent signal is substituted for the actual sensor output, and the measurement system is adjusted to the proper reading. The highest accuracy for this type calibration is obtained by signal substitution as close to the sensor as practical.

d. Generally, the accuracy of the calibration standard should be a factor of ten higher than the desired accuracy of the reading. In some *

* cases, a factor of three is sufficient, but this should be carefully researched.

e. Calibration should take place as close to actual and mean operating conditions as possible. For example a calibration taken at 70 F. may be innacurate when used at 0 F.

9-16. System Flexibility.

a. System flexibility is enhanced by choosing a general purpose system as opposed to a special purpose system. The first consideration for system flexibility is the number of input/output (I/O) channels and communications ports the system is capable of handling. I/O may be limited to the unit itself or expandable through an expansion chassis. Most systems are expandable by use of a communications port and an intelligent front end. Intelligent front ends can reduce the load on the main system through distributed processing. Another advantage is that they require less wiring and speed up system throughput. Intelligent front ends may also be used on remote sites where they can be controlled via a modem, or through radio transmission.

b. The more memory and storage capability a system has, the more flexible it becomes. The sample rate of a system can also influence flexibility. Features designed into a system, such as limit alarms, can increase flexibility. The amount and type of system power, as well as environmental specifications tend to restrict system flexibility. The type of system bus will influence the number of products that are compatible with that bus. A local area network (LAN) is a bus structure supported by several manufacturers, but which requires an intelligent controller. LANs can increase system flexibility by distributing access to the system. Many peripheral devices can be linked to the system by a single bus. This provides a convenient way to reconfigure the system by adding or removing devices.

9-17. Economic Factors. The material cost of the system is always an economic factor. The labor cost of programming, installation, check-out, and documentation must also be considered. Once the system is installed and working, maintenance becomes the major economic factor. The service offered by the manufacturer or his representative directly influences maintenance costs. Parts availability and cost also influence maintenance cost. The cost of downtime is a factor; the cost of expansion is another. The replacement projection and cost should be considered. When life-cycle costs are evaluated, a system which costs $10,000 and lasts five years isn't necessarily as good a buy as one which costs $20,000 and lasts ten years. *

* Section IV. Sensor Selection Criteria

9-18. Sensor Selection Criteria. Sensor selection criteria may be categorized into four general fields: 1) data requirements, 2) environmental requirements, 3) system considerations, and 4) economic factors. The System Requirements Document should clearly define data and environmental requirements relating to sensor selection. Table 9-l lists general data, environmental and system criteria which must be considered in selecting a suitable transducer for a given application.

9-19. Economic Factors. There are several economic factors to be considered in selecting sensors. They are as follows:

a. Accuracy. Specify only the required accuracy.

(1) - Special sensors add to cost.

(2) - Extra documentation adds cost; i.e., calibration record.

(3). More expensive transmission lines are required for highest accuracy.

b. Range. Choose a flexible range and an overrange which prevents sensor damage.

C. Temperature Compensation. Eliminate unless required.

d. Material. Must be compatible with media being sensed.

e. Shock, Vibration, Acoustic Bombardment, etc. Remotely locating the sensor can reduce shock. This may permit selection of less expensive sensors, simpler mountings, and less expensive cable.

f. Electrical Characteristics. Choose sensitivity, impedance, excitation to match the needs of the system.

g. Physical Characteristics (Size, Weight, Mounting). These are economic factors. Miniature sensors generally cost more; weight and custom mounting may be a cost factor.

h. Connectors. If connectors are not included, the cost of a single connector may be as much as $150.

i. Repairability. Repair charges are usually about 50% of the cost of a new sensor.

9-20. Sensor Hazards. Sensors are susceptible to damage and failure when exposed or subjected to certain hazardous conditions. Some general and specific sensor hazards at Corps sites include:

a. Over Excitation. With strain and temperature bridges, excessive current simply melts the wires in the bridge causing it to "open", or at least alter the sensitivity, linearity, and hysteresis of the sensor. Sources of over excitation can result from changes caused by line voltage variations, line transients, as well as a misadjusted power supply. Some power supplies produce up to +lOO% spikes when turned on. Proper excitation *

* turn-on procedures, the use of zener diodes as DC voltage regulators, and metal-oxide varistors (MOV) as power supply AC-line transient suppressors will minimize the chance of over-excitation damage to sensors.

Table 9-l

Sensor Selection Criteria

Data Requirements	Environmental	System
Range	Temperature compensation	Excitation
Overrange (limits)	Thermal zero shift	I/O impedance
Resolution	Thermal sensitivity shift	Sensitivity
Responsibility	Thermal shunt cal-ibration shift	Gage factor
Frequency response	Static acceleration	Shunt calibration
Residual unbalance	Vibration	Dimension, weight & size
Linearity/hysteresis	Acoustic bombardment	Mounting
Total absolute accuracy	Altitude & Humidity	Connector
	Magnetic	Insulation resistance
	Electromagnetic	Calibration
	Side axis response	Signal conditioning
	Nuclear	Reliability
	Thermal & Physical Shock	

b. Improper Polarity of Excitation. If connected backwards, the power supply may damage the sensors. Connect a diode in series with the power leads to prevent current from flowing when polarized backward.

c. Temperature Effects. Low temperature problems appear more often in civil engineering applications than those associated with high temperature. Some low temperature considerations are:

(1) Thermal Coefficient of Expansion. In sensors that rely on close dimensional tolerances, particularly between moving parts of different materials, differential expansion can cause damage to the sensor or inaccuracies in their readings.

(2) Freezing of Liquids. In sensors that measure liquids or make use of them in the measurement process, freezing temperatures can damage the sensor or cause measurement errors. Piezometers are constantly plagued with malfunctions caused by freezing of the water they measure.

* (3) Recording Devices. Certain recording devices do not function normally in low or freezing temperatures. Pen plotters which make use of liquid inks will not record properly, and display devices (particularly liquid crystal displays) do not function at temperatures below freezing.

d. Shock. Shock is defined as, "An abrupt impact applied to a stationary object." Any sensor may be damaged by shock, and some common sources of shock are:

(1) Shipping. Sensors are generally well packed to prevent shipping shock.

(2) Handling. Handling represents a source of shock damage. Dropping may easily subject a sensor to a shock of several hundred g's.

(3) Storage. Delicate sensors should be stored in compartments lined with shock-absorbent materials or in their original shipping containers.

(4) Sensor Installation. Some of the more prevalent poor installation practices are: applying excessive physical force when mounting or electrically connecting the sensor, installing a sensor to a test specimen before mechanical work is complete, touching exposed sensing elements, or using improper tools to mount a sensor.

e. System Checkout and Calibration. Sensors are sometimes damaged when a system checkout is being performed. Never exceed the maximum physical input capability of the sensor.

f. Cleaning. Sensors should only be cleaned with materials which do not harm them.

Section V. Signal Conditioning

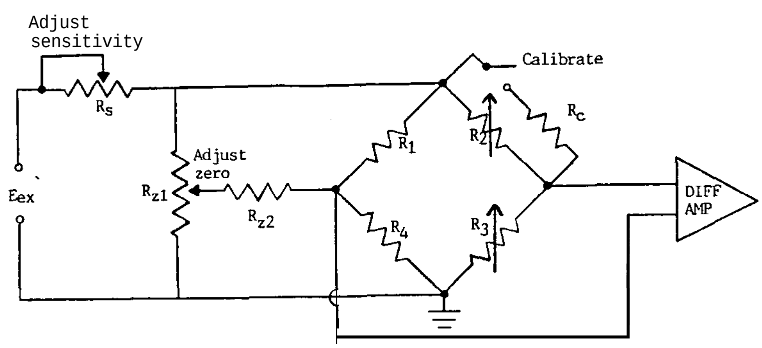
9-21. Introduction. Low-level electrical signals generated by basic measuring sensors generally need some form of "conditioning" before they are sent to the automated system processor or recorder. Such signal conditioning functions may require specific devices for certain classes of sensors (strain gage bridge), or they may be general purpose, as with filters, applying to a variety of signal transformations. Although certainly not exhaustive, the following types of signal conditioning are often required in the design of engineering measurement systems. *

* 9-22. Bridge Circuits.

a. The resistive strain gage and Wheatstone bridge network is used extensively as the transducing element in measurement systems. Strain gage bridge applications require special signal conditioning techniques with elements of bridge excitation, bridge balance, bridge completion, and calibration (Figure 9-l).

b. Bridge excitation supplies should generally be grounded and caution taken not to ground the output of the bridge. Output signals typically are applied to fully differential amplifier inputs of recorders, meters, or processor systems. Bridge excitation, Eex, must be a regulated constant voltage. Individual bridge sensitivities may be varied with the application of a series rheostat, Rs, allowing numerous bridges to be excited by one constant voltage source. Connection of a balance potentiometer, RZl and a series resistor RZ2, provides for adjusting the output voltage to be precisely zero. Resistor RZ2 should be kept as high in value as practical, since it shunts the bridge and reduces its sensitivity somewhat.

C. Strain gage bridges may be calibrated directly by introducing an accurately known resistance change, Rc "shunted" across R2, and recording the effect on the bridge output. A field effect transistor (FET) switch may be used to connect the shunt resistor, Rc, to the bridge, but it should operate at the input or guard potential, and be optically isolated from ground.



If $R_1 \approx R_2 \approx R_3 \approx R_4 < 1{,}000$ ohms (usual strain-gage transducer)

then $R_{z2} \approx 100\ R_1$

$R_{z1} \approx 25{,}000$ ohms

Figure 9-1. Bridge with Sensitivity, Balance and Calibration features.

* 9-23. Amplification. Signal conditioning functions such as buffering, isolation, gain, level translation, and current-to-voltage or voltage-to-current conversion are performed by operational amplifiers. Most sensor circuit techniques required for best design and implementation generally lead the prudent system designer to seek packaged, commercially available "system solutions", such as modular, multichannel DC instrumentation amplifiers. These instruments are characterized by excellent key amplifier specifications of input and output impedances, stability (drift), input bias current or offset current, gain, and common-mode rejection. Bandwidth is critical in applications of high frequency dynamic signals such as seismic accelerometer outputs. Most commercial instrumentation amplifiers have selectable bandwidths from DC to 10OkHz.

9-24. Instrumentation Amplifiers.

a. An instrumentation amplifier is a committed "gain block" that measures the difference between the voltages existing at its two input terminals, amplifies it by a precisely set gain, usually from 1 to 1000 V/V or more, and causes the result to appear between a pair of terminals in the output circuit. An ideal instrumentation amplifier responds only to the difference between the input voltages. If the input voltages are equal, the output of the ideal instrumentation amplifier is zero.

b. An amplifier circuit which is optimized for performance as an instrumentation-amplifier gain block has high input impedance, low offset and drift, low nonlinearity, stable gain, and low effective output impedance. Applications which capitalize on these advantages include thermocouples, strain gage bridges, current shunts, biological probes, preamplification of small differential signals superimposed on large common-mode voltages, signal-conditioning and moderate isolation for data acquisition, and signal translation for differential and single-ended signals wherever the common "ground" is noisy or of questionable integrity.

C. The most-important specifications in sensor interfacing are those relating to gain (range, equation, linearity), offset, bias current, and common-mode rejection.

(1) Gain Range. Values of magnitude 1 to 1000 V/V are common, but higher values are possible.

(2) Gain Equation. "Gain accuracy" specifications describe the deviation from the gain equation when the gain-setting resistor is at its nominal value. To take into account the lumped gain errors of all the stages *

* in the analog portion of the system, from the sensor to the A/D converter, systems using digital processing may be made self-calibrating.

(3) Nonlinearity. The magnitude of linearity error (or nonlinearity) is the maximum deviation from a "best straight line", on the plot of full-scale range output vs input. It is expressed as a percentage-of full-scale output range.

(4) Offset. While initial voltage offset may be adjusted to zero, shifts in offset voltage with time and temperature introduce errors. Systerns that involve "intelligent" processors can correct for offset errors in the whole measurement chain. In most applications, the instrumentation amplifier's contribution to system offset error must be considered.

(5) Input Bias. Input bias currents may be considered as sources of voltage offset (when multiplied by the source resistance). For balanced sources, the offset current, or difference between the bias currents, determines the bias-current contribution to error. Differences between the bias currents with temperature, common-mode level, and power supply voltage may lead to voltage offset or common-mode error.

(6) Bias Current Return Path. Although instrumentation amplifiers have differential inputs, there must be a return path for the bias currents, however small. If the path is not provided, those currents charge stray capacitances, which cause the output to drift uncontrollably or to saturate. Therefore, when amplifying the outputs of "floating" sources, such as transformers, thermocouples, and AC-coupled sources, there must be a DC "leak" from both inputs to common. If a DC return path is impractical, an isolator must be used.

(7) Common-mode Rejection. Common-mode rejection (CMR), is a measure of the change in output when both inputs are changed by equal amounts. Typical values of CMR in instrumentation amplifiers range from 70dB to 1l0dB. In the high-gain bridge amplifiers found in modular signal-conditioners, the minimum line-frequency common-mode rejection is of the order of 140dB.

9-25. Isolation Amplifiers.

a. The isolation amplifier, or isolator, has an input circuit that is galvanically isolated from the power supply and the output circuit. Isolators are intended for: applications requiring safe, accurate measurement of DC and low-frequency voltage or current in the presence of high common-mode voltage (to thousands of volts) with high common-mode rejection; line-receiving of signals transmitted at high impedance in noisy en- *

* vironments; and for safety in general-purpose measurements where DC and line-frequency leakage must be maintained at levels well below certain mandated minimums. Principal applications are in electrical environments of the kind associated with dams, large concrete structures, and field-portable instrumentation, The medium that is currently in widest use is transformer-coupling of a high-frequency carrier for communicating power to and signals from the input circuit.

b. One of the most important considerations about using an isolation amplifier is the manner in which it is hooked up. Since the more common sources of electrical noise arise from ground loops, electrostatic coupling, and electromagnetic pickup, the following guidelines concern the guarding of low level millivolt signals in hostile environments (also refer to Figure 9-2).

(1) Use twisted shielded cable to reduce inductive and capacitive pickup.

(2) Where possible, drive the sensor cable shield, S, with the common-mode signal source, EG, to reduce the effective cable capacitance

(3) To avoid ground loops and excessive hum, signal low, B, or the sensor cable shield, S, should never be grounded at more than one point.

9-26. Filtering. Conditioning analog signals with filtering is a method of attenuating or eliminating electrical signals of undesired frequencies. The four basic types of filters are: 1) low-pass, 2) high-pass, 3) band-pass, and 4) notch.

a. The low-pass filter is commonly used in low frequency data applications to eliminate signal noise that originates at the signal source or is picked up in data transmission. It passes low frequency data signals with little attenuation and attenuates amplitudes at high frequencies. The majority of structural measurements made by the Corps result in very low frequency data signals which can be low-pass filtered to increase signal-to-noise ratio and enhance accuracy. It is highly desirable to select a cut off frequency as low as possible for the sensor signal conditioning. A good guideline is to select a cut off frequency which is as low as the desired information from the sensor will permit.

b. High-pass filters characteristically pass high frequency signals and attenuate low frequency signals. Typically, high-pass filtering may be used in piezoelectric accelerometer measurements of seismic activity to minimize errors due to amplifier bias currents and high noise gain at low frequencies in charge amplifiers. *

* c. A band-pass filter is typically formed by cascading a low-pass and a high-pass filter of appropriate cut off frequencies to obtain the desired band-pass characteristics. It is used with low to moderately high frequency signals.

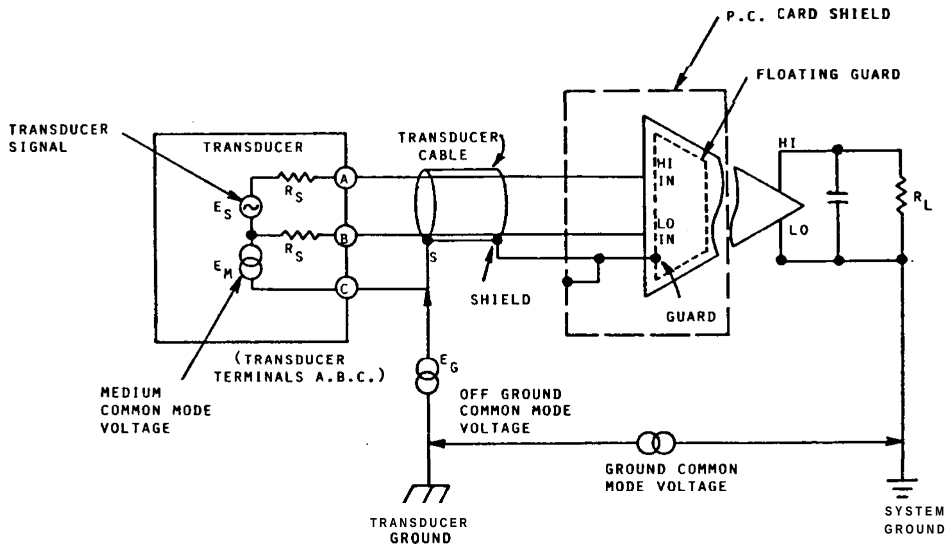


Figure 9-2. Sensor-Amplifier Interconnection

d. A notch filter is characterized by attenuating or "notching out" a narrow frequency band of an electrical signal. A common use of the notch filter is the rejection or elimination of 60-Hz power line interference in analog data signals.

9-27. <u>Signal Conversion.</u> Frequently, it is necessary to convert electrical signals from analog to digital form and vice-versa in large instrumentation and data acquisition systems. Signal conversions in these applications are generally of four basic types: 1) analog-to-digital, 2) digital-to-analog, 3) voltage-to-frequency, and 4) frequency-to-voltage.

a. The analog-to-digital converter (ADC) is the most widely used signal converter today. As the name implies, this device converts or *

* "digitizes" analog signals to a digital form. Conversion time, accuracy, and linearity are important parameters. There are two types of ADCs generally used in data acquisition systems: successive-approximation and integration.

(1) Successive-approximation ADCs are quite widely used, especially for interfacing with computers, because they are capable of both high resolution and high speed. Conversion time is fixed and independent of the magnitude of the input voltage. Since the accuracy of this type of ADC is dependent upon the input not changing during the conversion process, a "sample-hold" device is usually employed ahead of the converter to retain the starting input value.

(2) The integrating ADC is also quite popular. It performs an indirect conversion, by first converting to a function of time, then converting from the time function to a digital number using a counter. The dual-slope type is especially suitable for use in digital voltmeters and those applications in which a relatively lengthy time may be taken for conversion to obtain the benefits of noise reduction through signal averaging. Though too slow for fast data acquisition, dual-slope converters are quite adequate for such sensors as thermocouples and gas chromatographs.

b. The digital-to-analog converter (DAC) is used to convert digitally formatted signals to analog voltages or currents. The output of a DAC can be either current or voltage. Typical applications of a DAC include programmable power supplies, current sources, pulse generators, panel meters, and industrial process control.

c. Voltage-to-frequency and frequency-to-voltage conversion is a process of transforming electronic data signals from the analog domain to the time domain and vice-versa. Voltage-to-frequency converters (VFC) convert analog voltage or current levels to pulse trains or other repetitive waveforms at frequencies that are accurately proportional to the analog quantity. Typical applications for VFCs include FM modulation, frequency-shift keying, A/D conversion with high resolution, two-wire high-noise-immunity digital transmission, and digital voltmeters.

d. Frequency-to-voltage converters (FVC) perform the inverse operation of the VFC; they accept a variety of periodic waveforms and produce an analog output proportional to frequency of the input waveform. Frequency-to-voltage applications include programmable frequency switches in instrumentation, motor speed control, and voltage controlled oscillator (VCO) stabilization. In analog-to-analog data transmission, the FVC converts serially transmitted data-pulse streams back to analog voltages. *

* 9-28. Electrical Interferences.

a. Low level instrumentation signals are very susceptible to any number of electrical interferences, generating spurious, error-producing voltages that are orders-of-magnitude larger than the actual measuring sensor output. Electrostatic, electromagnetic, and radio frequency (RF) source interferences are frequently encountered. They require special conditioning and shielding techniques to minimize their effects on system measurement accuracy.

b. Electrostatic interference is a function of potential difference between two points. Any path, intentional or unintentional between these potential differences carries current and produces voltages. To minimize unwanted electrostatic signals, special shielding techniques such as the following are applied:

(1) Enclose low level signal carrying components in metal-shielded containers whenever possible and ground the container to earth or zero signal reference potential.

(2) Ground or connect shields at only one point in the general path of signal flow, to prevent voltage gradients along the shield.

c. The circuit in Figure 9-3 is designed to reject common-mode signals defined as voltage E. This voltage is a common-mode signal because it is impressed in "common" on both input leads. Often, this signal is called a normal-mode signal.

d. A second type of common-mode signal frequently encountered in instrumentation is the excitation voltage used in a strain gage bridge. If one corner of the bridge is grounded, then one-half of the excitation is common-mode and must be rejected. This circuitry is shown in Figure 9-4.

e. Instrumentation amplifiers are widely used to reject unwanted common-mode signals in data systems. A common-mode signal for an instrument amplifier is defined as the average input signal or:

$$E_{CM} = 1/2\ (E_1 + E_2)$$

and the differential-mode signal is defined as the difference voltage or:

$$E_{DM} = E_2 - E_1$$

Note that if $E_1 = 0$, the difference signal is E_2 and the common-mode signal is $1/2\ E_2$. *

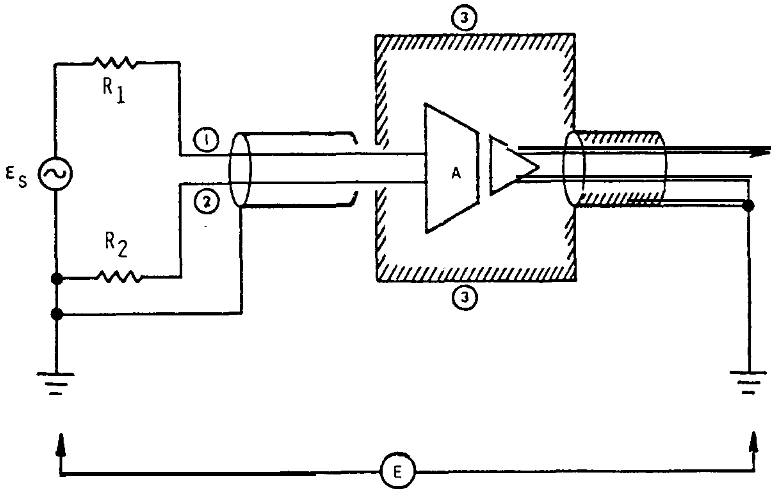


Figure 9-3. A Single Amplifier to Reject Signal E

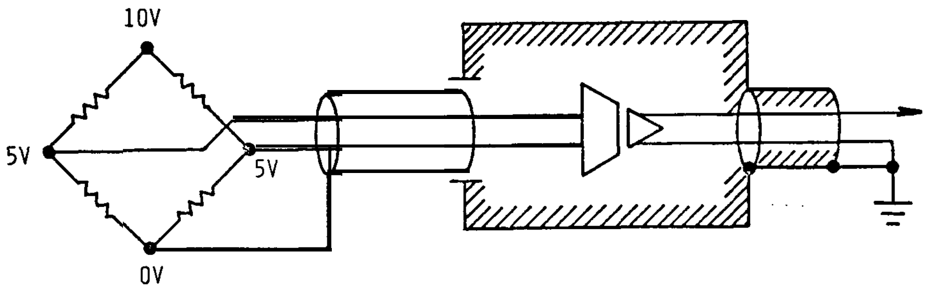


Figure 9-4. Excitation Voltage as a Common-mode Signal

* f. Changing magnetic fields result in electromagnetic radiation which induces stray currents and voltages in nearby conductors and circuits. At RF frequencies, even small capacitances appear as low reactances. For example, 100 pF is 150 ohms at 10 MHz. This means that nearly every conductor associated with a rack of instrumentation forms a ground loop with the ground plane and numerous other conductors.

g. Typical RF sources are radio, television, and radar. Also present are such devices as diathermy machines, arc welding, fluorescent lights, and glow lamps. Proper system grounding and shielding techniques preclude effects of RF interference.

Section VI. Data Transmission

9-29. Types of Data Transmission. The two basic types of data transmission are: cable and radio transmission. Radio is generally more costly on short links, and cable more costly in long links. The type chosen should depend upon economy and system needs. The cost of signal amplifiers, cable, and cable installation should be weighed against the cost of the radio transmitter, receiver, and antennas. When choosing a method of transmission, the three most important factors are distance, frequency, and environment. Generally, a short distance, low frequency link in a low electrical interference environment is the least expensive. The data may be transmitted in analog or digital form. Digital methods are less subject to interference, have the advantage of data verification, and can be transmitted serially or in parallel. The disadvantage is the requirement of digitizing the signal at the source. This requires a power source and analog-to-digital converters at the sensor end of the data link. Low level analog voltage signals are the most subject to interference. Most analog signals are transmitted as voltage levels over short distances, but can be transmitted as 4-20 mA current signals. Because the system operates from 4 to 20 mA rather than 0 to 20 mA, the presence of a 4-mA current confirms link connection.

9-30. Multiplexing.

a. Multiplexing is the sending of two or more separate signals over the same channel. There are two forms: time-division and frequency-division. Time-division breaks each transmission into segments of known time length and sends them serially. Frequency-division sends multiple transmissions on different frequencies at the same time. Several hundred signals can be transmitted in parallel over the same channel using this method. Multiplexing can reduce signal conditioning, cabling requirements, and the number of receivers, and sensors. *

* b. The disadvantages of multiplexing are mainly the requirement for power at the transmitter end, and the cost and maintenance of the electronics for the transmitter and receiver. The main advantage is that it reduces system hardware redundancy.

9-31. Network Configurations.

a. When designing a data transmission scheme, the three most common network configurations are centralized, loop and distributed. These configurations require intelligent controllers at each end and not merely signals from sensors, meters, etc. In a centralized system, data lines are connected to a central point where a controller handles most shared tasks (Figure 9-5). The advantages of a centralized network are simplification of network control and shared control hardware and software. The disadvantage is that host lines are dedicated and can not be shared with others.

b. In a loop configuration, the interfaces are serially linked in a circular manner (Figure 9-6). This works well when remote controllers are relatively close to each other. Communications interfaces are less costly for this configuration.

c. In a distributed configuration, intercommunications may be achieved by any node pair in the network (Figure 9-7). Its advantage is that a failure at one node does not affect the rest of the network. Its disadvantages are that it is difficult to control and requires a complex communications interface at each node.

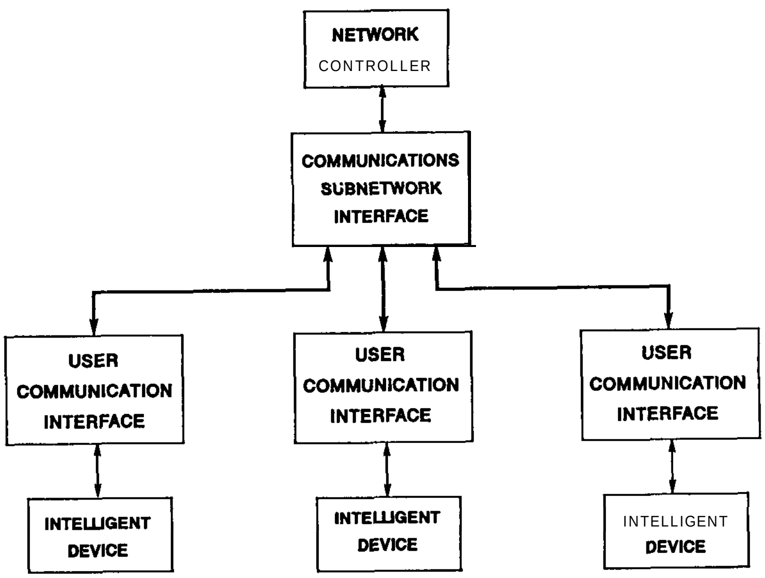


Figure 9-5. Centralized Configuration

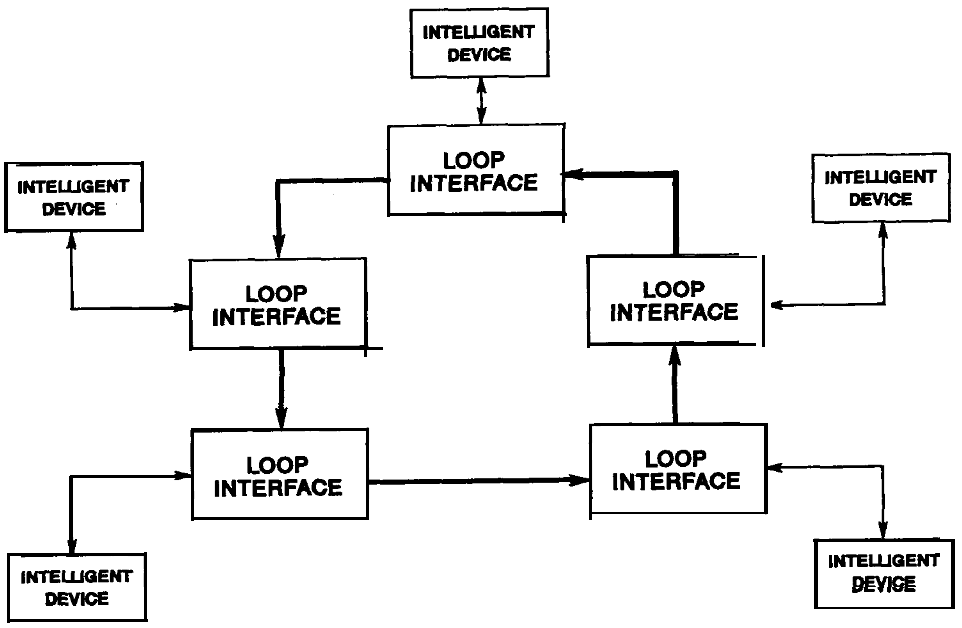


Figure 9-6. Loop Configuration

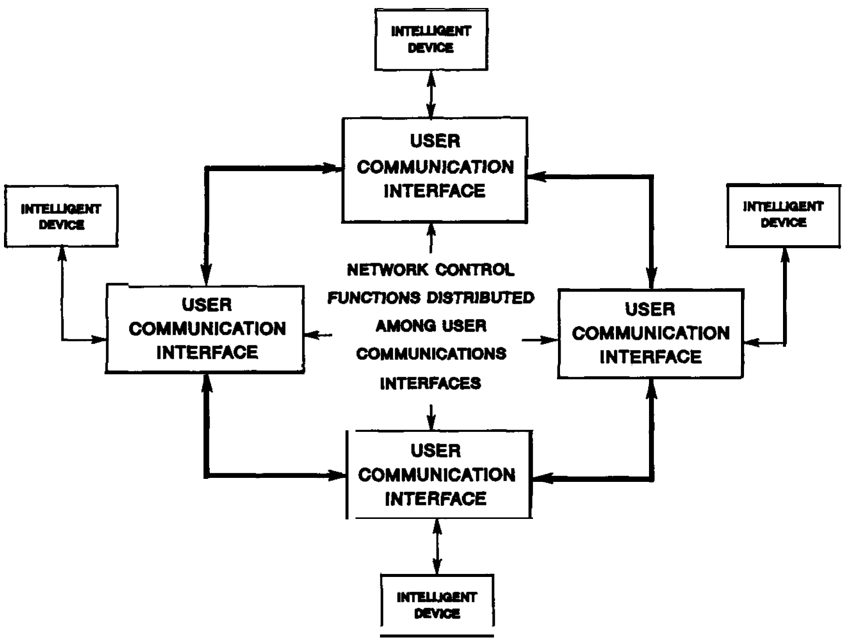


Figure 9-7. Distributed Configuration *

* 9-32. Transmission Techniques.

a. Cable. The most common and inexpensive form of transmission for short (one kilometer or less) links is electrical cable. Two types of commonly used cables are parallel wire and coaxial. Parallel wire cables are used for low-to-midfrequency and balanced line applications. Using twisted pair (signal and return) and/or an outer conductive shield reduces noise and interference. Coaxial cable is used for frequencies up to 18 GHz in unbalanced line applications. High-frequency transmission factors are: losses due to radiation and reflected power, characteristic impedance, and signal attenuation. Signals may be transmitted over cables in single-ended or differential modes. In the single-ended mode, the signal return is referenced to ground. In the differential mode, the receiver detects the difference between signal and return. Analog or digital signals may be transmitted in either mode. Analog signals can be corrupted by noise and the response characteristics of the transmission line. Digital transmission systems are not as easily corrupted and have the advantage of error detection and/or correction.

b. Fiber-optics. When noise or interference become intolerable, a fiber-optic link may be used. Fiber-optic links also provide electrical isolation. These are very high-speed links and have a wide bandwidth.

c. Radiotelemetry. When interconnecting cables are not possible or desirable, signals may be transmitted by radio. Radio signals may be amplitude, frequency or pulse modulated and may be analog or digital. Since radiotelemetry can become quite complex with problems associated with transmitters, antenna location and orientation, and noise interference; other forms of data transmission should be investigated first.

d. Satellite Transmission. A recent innovations in data transfer is the use of satellites to transfer information from one spot in the country to another. Data is transmitted from the site to the satellite via a radio transmitter. The data is then transferred to a ground receiving station where it can be further reduced and used for monitoring the remote operations. The equipment that is necessary to accomplish this transfer is called a data collection platform. It consists of a data collection unit, usually of an intelligent nature capable of making decisions under the control of a computer program, a transmitter, and a transmitting antenna.

9-33. Transfer Rate (resolution and accuracy). Transfer rate, sometimes referred to as throughput, is the number of readings or signals which can be transferred per unit of time, usually per second. If a serial digital transmission is used and has a 10K throughput (10,000 readings per second) with a 16-bit resolution, the transmission line must be able to support *

* more than 160 kbaud (adding control, error, and synchronization bits). Transfer rate is a controlling factor in the selection of a transmission method and usually has a direct relationship to cost. Usually, the higher the resolution, the higher the cost.

Section VII. Data Processing, Display, and Recording

9-34. Complexity. Data processing, display, and recording functions range from simple systems to very complex software-intensive computer systems. A simple system is a strip chart recorder. The data signal is conditioned, displayed and recorded in a single unit. Most low-end systems, such as strip chart recorders, supply raw data or data in a form which may not be used in other systems. Computer systems give the highest degree of flexibility for data processing, manipulation, display, recording, and storage.

9-35. Data Processing.

a. The vast majority of data processing is digital processing, analog processing is rare. Once digitized, the analog signal is input to the computer or data system as raw data.

b. At this point, the data volume is at its maximum. The raw data may be stored and/or recorded at this point. If the raw data are stored and then processed, this is called batch processing. If the data are processed as they are read, this is called real-time processing. Where speed is important, real-time processing is necessary.

c. The first step in processing raw data is usually to convert the data to engineering units. In this conversion process, calibration factors are often used to compensate for inaccuracies, and conversion factors are added to change electronic signals to readable, engineering values. The speed and flexibility of this process are influenced by the computer language used.

d. The following is a quick overview of the advantages and disadvantages of different languages for basic understanding.

(1) Machine Language. All other languages are ultimately converted to this type of code. It is machine dependent, very fast, but is an extremely difficult language in which to program.

(2) Assembly Language. The next highest level of language consists of acronyms which represent machine functions. It is called ASSEMBLY language. It is also a fast language, somewhat easier to interpret, but also cumbersome and difficult to code. *

* (3) High Level Languages. The high level languages are so called because they use English-like text for programming. These languages, although they are easy to program, are slow because they must be compiled or interpreted before they can be understood by the computer. BASIC is one of these languages, it is used quite frequently with personal computers. The most frequently used high level languages are COBOL, FORTRAN, and PASCAL. COBOL is a business language designed to handle large amounts of data with very little manipulation. FORTRAN is a scientific language designed to handle small amounts of data with a great deal of manipulation. PASCAL is designed to be a fast running language with some of the advantages of both COBOL and FORTRAN.

9-36. Display. Once data have been acquired and reduced, they must be displayed. The most common types of data display are as follows:

a. Printers:

Line printers	Dot matrix printers
Character printers	Daisy wheel printers
Letter quality printers	Electrostatic printers

b. Plotters:

Flat bed plotters	Multipen plotters
Moving paper plotters	Electrostatic plotters

c. Cathode Ray Tubes:

Monochrome	Color
High resolution	

d. Alphanumeric Displays:

Gas discharge displays	Light emitting diodes (LED)
Liquid crystal display (LCD)	Dot matrix displays

9-37. Recording/Storage.

a. Data that must be kept for later use needs to be stored when not in use. There are several types of storage, and each has its appropriate advantages. Random access memory (RAM) is storage that is meant for short term use. It is only a viable means of storage while the computer is on. When power is removed from the system, its contents are lost. For more long term storage magnetic media must be used. There are two types which are most frequently used. Floppy disk and hard (Winchester technology) disk allow for random access to data which is not lost when the system is turned off. Magnetic tape also retains data when power is removed, but in *

* order to get to information on the tape, all the data before it on the tape must be read. This makes it a slower method of retrieving stored data. The magnetic tape is also the less expensive type of storage.

b. Although magnetic tape and disk are the most commonly used methods of data recording and storage, other methods are available. These include punched cards, paper tape, and bubble memory. All of these methods are sequential and have advantages for specific applications.

Section VIII. System Design Document and Design Review

9-38. System Development. System development should start with two elements: a system design document and a design review process. Both these elements cause the development of the system to be well thought out and designed for the instrumentation purpose it was intended. System strength, capability, budget, space, and environment are all areas which need consideration. The system design document establishes the level of need and the constraints of the system. The design review process reviews what has been developed, refines the parameters, and prevents the occurrence of design oversights.

9-39. Guidelines for Preparation of a System Design Document.

a. After the system requirements document is complete, a block diagram and list of all hardware and software should be drawn. The list should contain at least those items given in Table 9-2.

Table 9-2

Items on Hardware and Software List

Part and model numbers	Number of units required
Description of the unit(s)	Options required
Accessories required	costs
Manufacturer or vendor with address and phone number.	

b. A site plan showing the placement of electronic cabinets, sensors, tables, etc., should be drawn. A detailed drawing of each cabinet with installed equipment should be included. Cable details should be prepared, showing signal line designation, cable type, length, connector types, and connector pin designations.

C. Power requirements for the system should be determined and a drawing prepared to show power boxes, breakers, cable routing, and line *

* conditioners or motor generator sets. Grounding details should be defined and drawn.

d. A form showing the type and format of data transfers between units should be prepared to save time in software development.

9-40. Guidelines for Conducting a Design Review.

a. The purpose of the design review is to determine if the design meets the design requirements set forth in the "System Requirements Document." The design review process should not be a new design definition session, it should nevertheless be flexible enough to incorporate legitimate changes and omissions.

b. The design review should cover the entire system. Every component should be examined to verify that it will perform its intended function, without interfering with other system functions. The more "what ifs" discussed, the better the chances that the system will operate properly. Control and alarm functions of the system should be carefully examined to determine if they sufficiently cover the needs of the entire system.

c. System hardware discussions should include the following:

(1) The number and type of sensors
(2) Type and location of signal conditioning
(3) Multiplexing
(4) Transmission techniques
(5) Signal conversions
(6) System interfaces
(7) Data storage and recording devices
(8) System capabilities
(9) System control and indication functions
(10) Electrical and physical environment
(11) Power requirements

d. System software discussions should include the following:

(1) Input data formats and polarity
(2) Operating system functions
(3) Languages used
(4) Memory management
(5) Memory capacity
(6) Data processing and storage
(7) Data storage formats

(8) Data recording and recording formats
(9) Operator interfacing with the system
(10) Overall system speed

Section IX. System Implementation

9-41. Detailed Design.

a. Those facts gathered from the system design document should be reviewed and incorporated into the detailed design. Design emphasis should be placed on site plans, power requirements, grounding plans, rack layouts, and cabling.

b. When required instruments must be fabricated in-house, fabrication drawings, wire lists, and assembly instructions should be prepared. Documentation of nonstandard instruments is critical, whether they are designed in-house or not.

c. Documentation of nonstandard units should be specifically detailed in a design document. The design document should include detailed specifications of the item to be fabricated. Specifications should include all constraints such as size, weight, power requirements, mounting, electrical, environmental, controls, speed, etc. An assembly manual should be prepared to assist in fabrication of the system. A technical description of the system should be prepared. It must include all information necessary for the operation and maintenance of the unit. This usually consists of electrical and mechanical drawings, a theory of operation, operating instructions, installation instructions, programming instructions, a parts list, and any other pertinent information.

9-42. Procurement and Receiving Inspection. The final system configuration will have an impact on the procurement and inspection process. If the final system configuration is purchased from a single manufacturer, the purchase agreement should include an on-site demonstration by the manufacturer to ensure that the equipment meets all applicable specifications. Trade-offs are involved in the procurement/inspection process and should be resolved before procurement arrangements are concluded. For some systems, an inspection at the manufacturer's plant and an on-site inspection may be desirable, others may only require an on-site inspection, while still others can be done by in-house personnel. Purchasing standard systems, subsystems, or components is recommended whenever feasible to reduce costs, and improve on documentation, maintenance, and spare part availability.

a. Procurement. The procurement cycle normally commences with the final approval of system design. After design approval, a determination of *

* long lead time items should be made in order to establish an ordering priority list. When standard components are ordered by manufacturer, model number, etc., the technical specifications need not be stated on the procurement document. However, when nonstandard equipment is procured or competitive bidding is required, all specifications must be stated on the procurement document. Other requirements on the procurement document include:

(1) The need for a source (manufacturer's plant) inspection. A more reasonable approach is to have an on-site inspection for larger systems and an in-house inspection for small systems and components.

(2) All system options. Some manufacturers tend to offer several versions of a system to accommodate multiple-user requirements.

b. Receiving Inspection. An inspection plan should be prepared to delineate the type of inspection to be performed. It should define the type of documentation to be maintained; the procedure to be followed when material or articles do not conform to applicable drawings, specifications, or other requirements; and the acceptance/rejection criteria.

(1) A physical inspection of all incoming equipment should be made. Those articles which require no further inspection should be sent to the designated system assembly storage area; those articles which require acceptance testing and/or calibration should be sent to the responsible testing authority. All articles damaged by the common carrier should be documented, and the carrier should be notified so that remedial action can be taken.

(2) All sensors, instruments, and subsystems which contribute to the overall system accuracy and operation should be acceptance tested and/or calibrated. All nonfunctional hardware, such as cabinets, etc., may be visually inspected. Records of all inspections and tests performed should be maintained. These records show the initial status of an instrument and substantiate nonconformance or failure during the warranty period.

9-43. Acceptance Tests. The objective of acceptance tests is to verify that material and articles meet the supplier's stated specifications or the actual application requirements. Generally, the manufacturer's test/calibration procedures are followed to verify that specifications are met. When applicable, test data should be recorded and retained. When material or an article fails the acceptance test(s), it should be so noted and a determination made as to whose responsibility it is to make repairs *

* and/or adjustments. In some special cases, a supplier or his representative makes on-site corrections, especially when large single source systems are involved or when specifically stated on the procurement documents.

9-44. Metrology Controls.

a. Generally, there are components within an instrumentation system which should be calibrated and placed in a documented metrology control/recall system. The documented metrology system should provide evidence of quality conformance. Components normally placed in a metrology control/recall system are: sensors, amplifiers, filters, voltmeters, analog-to-digital converters, and calibration standards. These components should be assigned calibration intervals based upon manufacturers' recommendations, or the recommendations established in standard Government manuals. The calibration intervals should be reviewed periodically and adjusted to insure recalibration on a timely basis. In establishing intervals, consideration should be given to the use, accuracy, type of standard, required precision, and other conditions adversely affecting quality.

b. All standards and equipment used in measurement processes should be in a recall system. Controls should be established to ensure that those instruments which are not calibrated within the established interval be immediately recalibrated or removed from service. All equipment in the recall system should have a label or tag affixed to indicate the calibration status and due date of the next calibration. The calibration record system should provide sufficient information to determine calibration results, traceability to the NBS, date of calibration and the interval or next calibration date.

9-45. System Fabrication.

a. If turnkey systems are not procured, the decision to make or buy a piece of equipment should be made promptly so that system integration and installation is not delayed. If fabricated in-house, several categories of component devices are likely to need special attention. They are mounting brackets, cables and wiring, cable troughs, and electronic interface devices. The quality of materials used, clarity of panel markings, routing of cable harnesses and the placement of clamps, and general workmanship during the fabrication process need attention.

b. Detailed electrical and mechanical drawings should be prepared before fabrication commences. Other documentation, such as hardware and electronic component specifications, input/output voltage levels, and *

* impedances should be specified. The documentation will be required regardless of the source of fabrication.

9-46. <u>System Integration.</u>

a. Hardware integration consists primarily of cabling all units together. Problems with missing cables or cables with the wrong size or type connectors are found and corrected. At this time each cable should be tagged, so that when the system is packaged for delivery to its permanent location, all cables will be properly identified. Regarding warranties, each manufacturer has specific rules regarding what voids a warranty. Therefore, before opening a unit or removing its covers, the owner's manual or warranty card should be checked.

b. The application of AC power to the system should be done slowly, carefully, and unit by unit. Although each unit was verified as operating properly during acceptance testing, it may have developed problems or the interface cabling may be incorrect. After power is applied to all units of the system, each unit should be verified as being operational.

c. Software integration is very similar to hardware integration. First, the computer is verified as operational by running the appropriate CPU and memory diagnostic. Then each standard peripheral such as disks, tape drives, and printers, should be verified using standard diagnostics. The nonstandard devices such as A/D converters, multiplexers, and other signal conditioning equipment must be verified with purchased or self-written diagnostics. Next, the computer operating system (OS) should be loaded, with drivers to operate all peripherals ready for testing.

d. The final checkout phase of system integration consists of verifying the proper operation of the data acquisition program with all system hardware. This verification should closely simulate the site-installed configuration. Interface cables of the same length as those to be installed at the site should be used. A complete set of sensors similar to those at the actual site should also be used or simulated as closely as possible. As the last step in the system integration phase, the final hardware and software configuration should be documented in the system installation manual.

9-47. <u>System Installation.</u>

a. System installation actually begins during the system design phase when the physical layout or site plan is drawn. Corps sites are often environmentally harsh and hazardous to automated instrumentation. The area which houses the main components of the system should be thoroughly *

* cleaned and the cooling/heating systems verified just before the arrival of the system. Dust, especially concrete or cement dust, from construction or renovation causes air flow filters to clog and magnetic media to be severely damaged.

b. In areas that are subjected to wide temperature variations and water/moisture exposure, instruments should be enclosed in environmentally-conditioned cabinets or rooms. To reduce moisture condensation and corrosion damage and limit temperature excursions, simple electrical heater strips or light bulbs may be installed within the instrument enclosure or room. A commercial-grade electrical insulating varnish or equivalent coating should be sprayed over all exposed electrical connections to protect them from corrosive moisture.

C. To preclude physical damage to instruments and equipment, they should be installed in metal cages, cabinets, or equally sturdy enclosures or shelters. To limit the damage by vandalism, all equipment (instrumentation and cables) should be enclosed in protective shelters and, if possible, hidden from normal view. All enclosures that are exposed to weather and public access should be environmentally protected, and fabricated with steel plating and padlocks.

d. Upon arrival at the site, the equipment should be physically placed in accordance with the site plan. Before connecting cables between units, and applying primary power to each unit; the outlet or junction box should be checked for proper wiring and grounding.

e. After all equipment is in place and all cables are connected, power may be applied to the system and the check-out phase of the installation may commence.

f. Final acceptance of the system also affords a good opportunity for user training. Having the system user perform all functions and tests that are to be implemented, not only tests the operability of the system, but also allows the user actual hands-on training.

g. As the last step in system installation, the system installation manual should be verified against the installed configuration. Any discrepancies should be resolved so that the information in the manual reflects the actual installation. Any changes that have been made during the installation must be properly noted. *

* 9-48. Documentation.

a. All system documentation must be maintained and updated throughout the life of the system. Documentation for individual units of the system is covered in Section X, Maintenance.

b. System documentation, unlike unit documentation provided by the equipment manufacturer, normally must be written specifically for each system. The primary purposes of system documentation are: how to operate the system; how to modify the system to add more hardware or changing the software; and how to maintain the individual components of the system.

c. The operations manual should include step-by-step procedures for all functions normally performed by a system operator. It should include what to do when things are working correctly, and also what to do when things are not progressing according to the procedures.

d. The system theory manual may in fact be more than one manual as both the hardware and software that make up the system need to be addressed. The hardware manual or section should, as a minimum, include the final system requirements, system design documents, a system level block diagram, and a written theory of its overall system operation. The software manual or section should contain a system level flow chart depicting the major software activities, a brief theory on the major portions of the program, and a table or tables depicting error messages, alarms, and predetermined set points or interrupts that automatically modify system operation. It should also include complete program listings containing comment statements for clarity of meaning.

e. At least two complete sets of documentation should be supplied with the system. One set should remain with the system; the other set should be maintained at a central location for reference by engineers who have responsibility for system maintenance or modification.

Section X. Maintenance

9-49. Maintenance philosophy. Developing a system maintenance philosophy is an intricate process requiring forethought and planning. Some of the elements which must be resolved are: the complement of maintenance technicians, a centralized or decentralized program, number of spare units or components to be maintained, and the amount of system downtime that can be tolerated. Once these answers are found, the overall maintenance program can be developed. A well-planned maintenance program results in a system which performs as expected and remains operational for many years. *

* a. Establishing a Philosophy. A maintenance philosophy should be undertaken early in the system design stage, and funds for its maintenance budgeted. A well-designed, automated system is of little use if it fails and can't be repaired due to a lack of manpower or material budget.

b. Types of Maintenance. Maintenance can be of three types: contract maintenance, self-maintenance, or some combination of the two. The decision must be based upon cost, in-house knowledge and manpower. Total contract maintenance requires the least amount of in-house skilled manpower, but may be the most expensive solution. Total self-maintenance requires the greatest complement of skilled manpower, and may lower maintenance costs. A combination of the two offers the technical skill of others, with the lower costs of self maintenance, and can produce a balanced product of experience and reasonable cost

C. Repair Philosophy. Repair can be centralized or localized. The chosen repair philosophy will depend upon criticality of the measurement being taken, cost, in-house expertise, and the level of replacement parts that the organization is willing to keep on hand. Board or subassembly "swapping" is the fastest method of achieving repair, and requires very little technical knowledge or equipment to achieve. The bad board is merely swapped out for a good one and the defective board repaired. However, it does require a large inventory of spare parts to be kept on hand. Choosing the alternative, fixing the unit in-house or sending it to a repair service, means taking the equipment out of service for a length of time. On site repair requires the most manpower, level of training, and inventory of parts. Sending the part or unit to a regional, or national repair service relieves the need for these items, but necessitates more time out of service for the unit.

9-50. Preventive Maintenance.

a. Each manufacturer normally includes, as part of the operations or maintenance manual, a section on the frequency schedule and activities that should be performed to verify proper operation and to prevent failures. These should be used to develop good preventive maintenance (PM) habits. A "master" or system PM schedule must be developed which includes recommended PM on each component of the system. The manufacturer's recommended frequencies must then be reviewed, modified, and checked against performance histories of the instruments in similar conditions to determine the frequency of maintenance for the environment in which the system is operating, i.e., increasing the PM frequency on a component if its environment warrants the extra protection. Providing an idealized environment for a system will reduce the frequency of maintenance required. These schedules should be checked periodically to insure that they are sufficient. *

* b. In the absence of manufacturers guidance on PM, reference to the recommendations for similar instruments under similar environments is advisable. The type of PM depends upon the instrument. A totally electronic instrument requires only an occasional cleaning; however, one with fans and filters must be cleaned and checked for proper air flow at a frequency dependent upon the operating environment. Electromechanical and mechanical instruments however, require periodic cleaning and lubrication. If there is doubt about the frequency of a PM check, a conservative stance, with more frequent PM checks is recommended.

c. The installation of data acquisition systems at unmanned remote sites presents entirely different problems. The previously developed PM schedule may be totally impractical because of manpower shortages or extremely difficult access. Under such circumstances, a trade-off between manpower and the loss of all or a part of the system must be made. Therefore, any visit to a remote site to correct a known problem or to collect data, etc., should be combined with a PM visit.

9-51. Calibration.

a. To assure that accurate data are collected by the data acquisition system, the various units of the system and the system as a whole require calibration. The type, accuracy, and frequency of calibrations must be addressed during the system design.

b. During the acceptance process, each unit should undergo precision calibration. All sensors, especially those that are inaccessible after installation, should be verified for proper operation and accuracy by a competent calibration laboratory. All sensors should come with calibration data sheets, and digital instruments need only be verified for correct operation.

c. Once the system is put together, it should be calibrated by using an electronic voltage standard in place of the actual sensors. At this time, true system operation and accuracy may be tested and verified.

d. Periodic calibration of the system should be done. Manual calibration requires that a standard voltage be substituted for the sensor output. This known input used with a software calibration program allows verification and adjustment of the system for proper readings.

e. Automatic system calibration requires the installation of a programmable voltage standard, associated calibration relays, and a calibration program. This method allows calibration of the system by the repair technician after a repair or PM and without additional test equipment. Ef- *

* forts should be made to inject the calibration signal as close to the sensor output as possible. This will give the highest level of confidence in the overall level of system performance. The frequency at which an automatic calibration can be run is practically unlimited, as it may be programmed to require no operator/technician intervention. The output of the calibration program may be evaluated by the processing unit, and failures or out-of-tolerance readings can be used to trigger either local or remote alarms.

f. Signal conditioning equipment returned from repair requires recalibration. Each unit must be calibrated or aligned to meet the manufacturer's specifications.

9-52. Documentation.

a. The purchase agreement should require each equipment manufacturer to provide sufficient documentation to facilitate the component level repair, alignment, and calibration of their respective instrument. Three major categories of documentation are required to properly maintain any unit of electronic or electromechanical equipment.

(1) The Reference Manual. This document should contain basic information on the functional use, programming, and basic input and output parameters of the unit. This manual is to assist the maintenance technician during the problem identification phase of repair. It answers many important questions such as: how the unit operates, its correct input and output format, and if it is functioning properly.

(2) The Service Manual. This describes the causes for certain failures, and how the technician isolates and repairs these problems. This manual normally contains a unit theory of operation, calibration information, as well as a breakdown of the major assemblies and subassemblies and a theory of operation for each. Depending upon the type of unit covered by the service manual, there are other helpful hints for the repair technician such as: troubleshooting procedures, signal and test patterns, spare parts lists, PM procedures, and manufacturer assistance procedures.

(3) The Drawing Package. Schematic or logic diagrams which are absolutely necessary for component-level repair of assemblies and subassemblies are contained here. Also, this package usually contains an illustrated parts breakdown (IPB) and the mechanical drawings of all component hardware.

b. The system integrator, vendor, or controlling engineer should be required to provide a system installation or system configuration manual. *

* This must be updated to reflect the actual configuration of the system after installation and acceptance. Additions, deletions, and any modifications to the system should be documented in the system installation manual. The system installation or configuration manual should contain as a minimum the following:

(1) Site plan (equipment locations).
(2) Power wiring and power source drawings.
(3) Cable routing and identification drawings.
(4) Computer bus priority scheme.
(5) Computer bus addressing, or unit recognition scheme.
(6) Unit identification (manufacturer, model, and available documentation for the unit).
(7) List of applicable software tests and diagnostic programs with instructions on how to run them.

c. The permanent location of each manual will depend on the maintenance philosophy chosen. Reference, service, and site installation manuals should be at the equipment site or carried to remote sites by a technician. If site, regional, and national centers are used for repair, copies of each manual should be located at each center. This documentation also provides quick reference for the engineer who is tasked with upgrading or modifying an existing system.

9-53. <u>Maintenance Software (diagnostic).</u>

a. Diagnostic software of different levels is required for maintenance troubleshooting of computer system hardware. The first level of on-site diagnostics should be developed or modified for each specific system and used as an operational readiness test. First level software only needs to verify basic communications between units, and fundamental operations of each device such as: 1) Are the sensors connected to the system? 2) Are the sensor readings reasonable for existing conditions? 3) Can the magnetic medium write, read, etc? Additionally, an on-line/off-line calibration diagnostic program should be incorporated into the system software. Although it is more time-consuming to run than the operational readiness test, a thorough system calibration program is used to find units which, although functional, are not operating within specifications and require replacement, alignment, or recalibration.

b. Diagnostics for subassembly or module level maintenance and troubleshooting are very complex and time consuming to run. They are device-specific and must verify all functions of a device. This type of diagnostic program is normally available from the equipment manufacturer and should be purchased simultaneously with the equipment. *

* c. Software for automated calibration of sensors and signal conditioning devices is also a necessity if the devices are to be calibrated on site. This software may be purchased from equipment manufacturers and customized for specific system configurations, or developed from "scratch".

d. If the data acquisition systems are on-line to central points of data collection, a remote diagnostic feature may be used to save a significant amount of time and effort. A remote diagnostic permits the technician to run and evaluate the operational readiness test and the system calibration program. This procedure informs the repair technician about a problem before leaving the central site and helps in preventive and corrective maintenance situations.

9-54. Spare Parts. The establishment of a spare parts inventory, whether at the component, subassembly, assembly, or unit level of maintenance, or at some combination of these, is a must. The depth of the spare parts inventory is governed mainly by the budget available and the failure history of the parts. However, false economies in the establishment and maintenance of a spare parts inventory can result in significant costs in manpower and lost system availability. At all but the component level of repair, it is far more economical for the person troubleshooting a problem to "swap out" a suspected faulty part than to take the time to isolate the malfunction with elaborate test equipment. The decision on what should be included in the initial inventory of spare parts to support a data acquisition system should be made based upon a combination of each equipment manufacturer's recommendation; the known history of the equipment, if available; and experience gained in maintaining similar equipment.

9-55. Test Equipment.

a. The choice of test equipment depends largely upon the level of maintenance to be performed. For assembly or unit level of maintenance, where diagnostic software and operational readiness tests are used to locate an inoperative unit, only the very basic test equipment is required. A complete electronic technician's tool kit, which includes a hand-held multimeter and a data communications tester, is sufficient.

b. For subassembly- or module-level maintenance, several more sophisticated pieces of test equipment are required in addition to those previously specified. These tools are shown in Table 9-3. Most of these repairs are done at the regional or central repair facility. *

* 9-56. Training.

a. Training is a basic requirement regardless of maintenance philosophy. An untrained technician can cause more delay and damage than there is actually present. There are several levels and types of training. The most basic level of training is knowledge of unit "swapping".

Table 9-3.

Necessary Maintenance Test Equipment.

Assembly/Unit Level Repair	Subassy/Module Level Repair	Component Level Repair
1. Complete ET tool kit 2. Hand-held VOM 3. Data communications tester as appropriate	1. All of Assembly level equipment plus 2. Portable 35-MHz dual-trace oscilloscope 3. Bus exerciser/analyzer (type depends upon bus) 4. Portable voltage standard 5. Digital multimeter 6. Master skew tape & master output tape for systems using magnetic tapes 7. Disk exerciser, alignment disk, & scratch disks for systems having disk drive units	1. All Assembly and Subassy level equipment plus 2. Bench type 100-MHz oscilloscope 3. Logic analyzer (time & logic state) 4. Microprocessor troubleshooter 5. One of each unit to be maintained to be used as a test fixture for troubleshooting & verifying repair

b. Of primary importance, the technician should be able to remove and apply source power to the system and to the individual units that make up the system. The second item is how to load and unload the storage media, magnetic tapes, or disks. This includes performing the actual physical act and informing the system that the recording media is replaced. Also, the first level maintenance technician should know all system operator functions for the specific system, as well as preventive maintenance functions. For a computerized system, the operator/technician also needs to receive training on the software operating system, system operating corn- *

* mands, the system operational readiness test, calibration programs, and hardware diagnostic programs.

c. The second level of training should cover assembly and subassembly level of repair. This requires an electronic technician who has received training in the fundamentals of electricity, basic electronics, digital theory, use of general electronic test equipment, and the fundamentals of computer systems and peripherals. Specific unit level training should cover special alignment, adjustment, field calibration procedures and use of diagnostic software for each unit.

d. The final level of repair, circuit component isolation and replacement requires the theory of operation of all electronic circuits and electromechanical and mechanical components in each unit. Advanced-level training in electronics, digital theory, computer systems, and in the use of advanced-level electronic test equipment should also be given.

e. System maintenance training, regardless of the level, must be customized for the specific system. The simplest and by far the most economical method of conducting this type of training, especially when turnover of personnel is high, is by the use of video training tapes. This method of training is also ideally suited to both preventive and corrective maintenance procedures. It allows the viewer to see the procedure actually being performed, and demonstrates techniques in minutes that would take chapters in a manual to describe.

f. The most formal and overall the most expensive type of training is the manufacturer's factory school. It generally takes place at the equipment manufacturer's facility. It is normally taught by a trained professional instructor and normally delves deeply into the theory of operation of the equipment. If the course includes laboratory time, actual hands-on training accompanies the theory training. This type of training also requires the loss of availability of the technician(s) for the duration of the course.

Section XI Retrofitting

9-57. Definition. In terms of instrumentation automation, retrofitting represents any effort to modify existing instruments so that they may be monitored completely under automated control, or such that the modification will aid instrumentation personnel in collecting the instrument data.

9-58. Need. The Corps has one of the largest investments in structural safety related and design related instruments in the entire country. Over the years, this investment has accumulated into the hundreds of millions of *

* dollars in instrumentation. Although some of these instruments are over fifty years old, they are still in working condition and still serving a useful purpose. Keeping these instruments working rather than replacing them is in the best interests of overall economy of the cost of maintaining a structure.

a. Retrofitting instrumentation that is already in place is beneficial in a number of respects. The cost of installing the instruments themselves is a large part of the cost of automating a monitoring task, making use of existing instrumentation, in this respect, will greatly reduce the overall cost of any automation operation.

b. The conditions under which the retrofit will be made bear heavily on the decision to proceed in this direction. If the instruments, or the structure in which they are installed only have a limited remaining useful life, then retrofitting will provide the needed benefits at the smallest cost. Installation of new instruments usually would not be economical.

9-59 Degrees of Retrofit. With the large diversity of instruments which the Corps uses, it is impossible to be able to apply retrofitting techniques to all of them. Some currently installed instruments, such as the inexpensive crack and joint measuring devices (Monolith joint displacement indicator, Relative movement indicator, Ball-n-box gage, scratch gage, etc.) cannot be retrofitted, or would be prohibitively expensive to do so. These instruments cannot be automated, and should be replaced with instruments which lend themselves to automation if the action is necessary.

a. Other instruments can be automated, but in order to use them the physical presence of an operator is necessary. A typical example of this class of instrument is the optical plummet. The method of reading an optical plummet requires an operator to sight, through the plummet telescope, at a target somewhere along the length of the vertical plummet shaft. In order to make the reading the operator must move the telescope to coincide with the center of the target. The movement of the telescope is then recorded. At present there is no mechanism which can determine that the telescope is aligned with the center of the target; and as such, an operator is necessary. However, there are electronic recording devices which can record the changes in movement of the telescope which the operator has made, and thereby help the operator make accurate measurements, help eliminate misrecorded data, and generally speed up the data collection process. These types of changes to a manual data collection system will partially automate the process. *

* b. The majority of the instruments used by the Corps produce some form of electrical output which can be measured by an electronic recording device. In most cases, these types of instruments can be fully automated by the addition of electronic data acquisition equipment, and in certain cases, by mechanical apparatus which perform the duties of an operator.

9-60. <u>Retrofitting Analysis.</u> Before considering a retrofitting operation, an analysis of whether the instrument retrofitting would be more cost effective than purchasing new equipment should be made. Cost factors such as age of the equipment to be retrofitted, cost of peripheral equipment which must be purchased to make the retrofit possible, as well as their installation costs must be weighed against the cost of new equipment and their installation costs before a wise decision regarding automation can be made. It is also important to consider accuracy and resolution of the older instruments, frequency of the data collection operation, and the information which is needed about the structure before making the decision on how to proceed.

9-61. <u>Necessary Components.</u> Sections II, III, V, VI and VII of this chapter give detailed information about the components which must be put together to design an automated data acquisition system. Retrofitting is an identical procedure, except that the instrument to be automated already exists, and must be supplimented to automatically collect its measurement. All other components of the automation process remain the same.

a. With respect to instrument output, there are two types of instruments the Corps uses. Either the instrument produces a change which must be physically measured, or it produces an electrical response to the change being measured. As mentioned before, the electrical response type instruments can be completely automated. However, those instruments which require a physical measurement in order to get the final data, generally require the interaction of an operator. In the cases where it is not possible to replace the operator, either the gage must be replaced to one which can be automated, or a partial automation must be sought.

b. Gage replacement requires the abandonment of the old gages and installation of new gages which give an electronic signal as output. A typical example would be to replace a crack measuring gage which requires an operator, with a surface mounted strain meter that outputs change in resistance or change in signal frequency as a function of strain. This type of instrument could then be automated completely.

c. In the event that the instrument is not to be replaced, and a partial automation alternative chosen, the operator would still be necessary to make the reading of the gage. Generally, some type of *

* electronic recording device which the operator could use as an electronic notepad would be used to aid in the automation. Rather than writing the measured output down on paper, the collected data could be entered into the electronic notepad. These types of devices can generally be programmed such that the information entered can be checked against historical data and a warning given if there are gross mismatches; or the data entered can be reduced to engineering values. The data which is now temporarily stored in the recording device can be electronically input into a computer in the engineering office through a standard serial or parallel interface.

d. Some instruments which require the presence of an operator come equipped with the capability to automatically store the data they collect. An example is some of the newer theodolites. These instruments must be aimed by an operator, but the output is automatically stored or transferred to a computer. This eliminates the mistakes which can be made in manually transferring the data to output sheets.

e. Partial replacement of some types of instruments which the Corps uses will allow them to be completely automated. The addition of a transducer which monitors some physical change and produces an electrical output can be used to automate an instrument. Piezometer standpipes are a typical example. Standpipe type cells may be measured by one of two methods. In one case, the water head at the cell is less than the elevation of the reading station. To retrofit this type of situation, a pressure sensor would be lowered in the standpipe to a level below the lowest expected water level. The pressure head on this sensor would then be an indicator of the elevation of the water in the standpipe.

f. The other method for measuring standpipe pressure may be used when a water pressure exists at all times at the reading station. Currently, dial type gages are used for measuring this pressure. The water pressure at this station may be diverted to a pressure transducer and the electrical output from the transducer monitored.

g. Those instruments which give electrical output, but were designed to be manually operated can be automated by devising a means of mechanically reproducing the actions supplied by the operator. For example, certain types of inclinometers are designed to be manually lowered down a casing and held at different elevations while an electrical signal is recorded. The first step in automating this type of instrument is to build a device which will lower (and raise) the inclinometer to predefined elevations at regular time intervals. A properly geared stepping motor attached to the reel containing the inclinometer cable could be devised which would lower the inclinometer into the casing. The stepper motor *
would halt the inclinometer at the predefined location and a signal could

* be sent to a data acquisition system to make a reading. The procedure would then be repeated until the entire casing had been read. This type of retrofitted instrument would be connected to a data acquisition system just as if it had been designed to be automatically monitored. *